New Areas of Automotive NDE: Li-ion Batteries and Composite Materials

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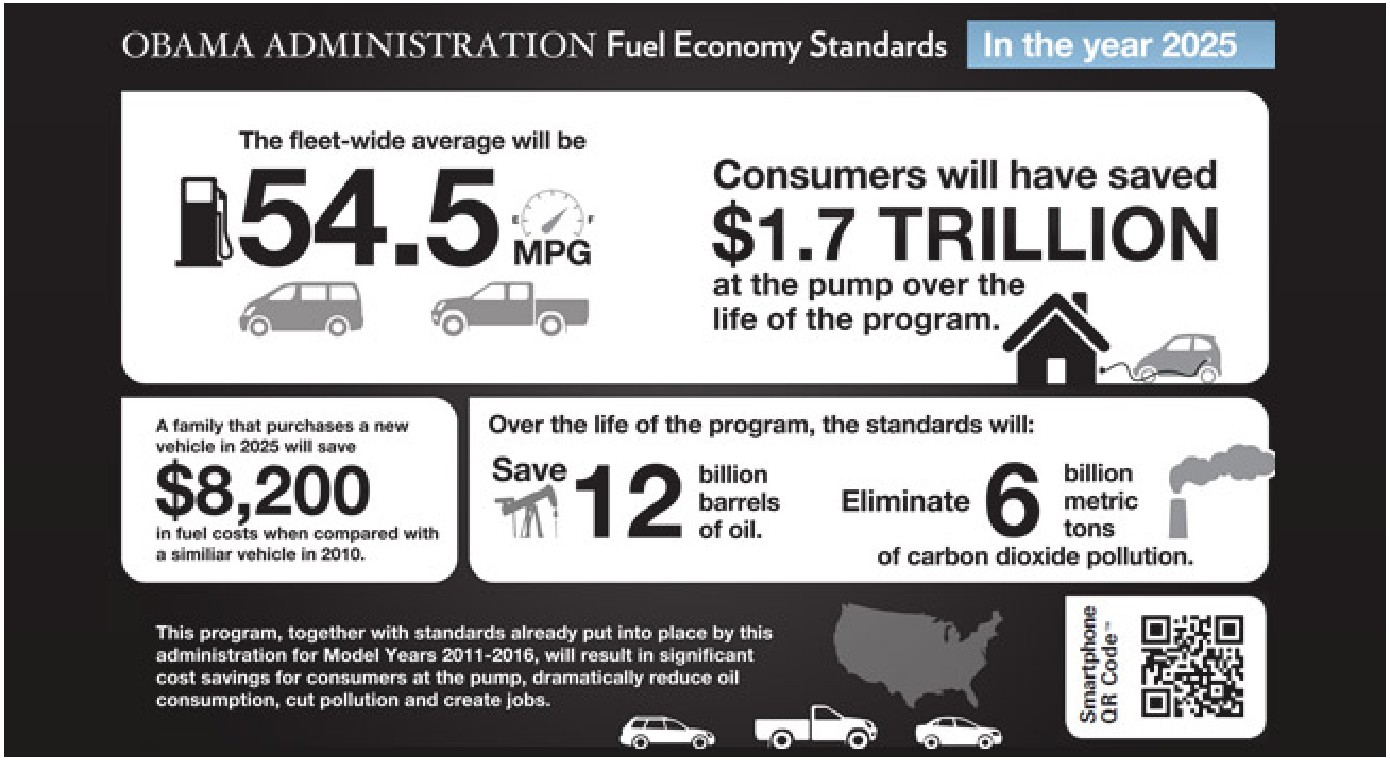
General Motors R&D

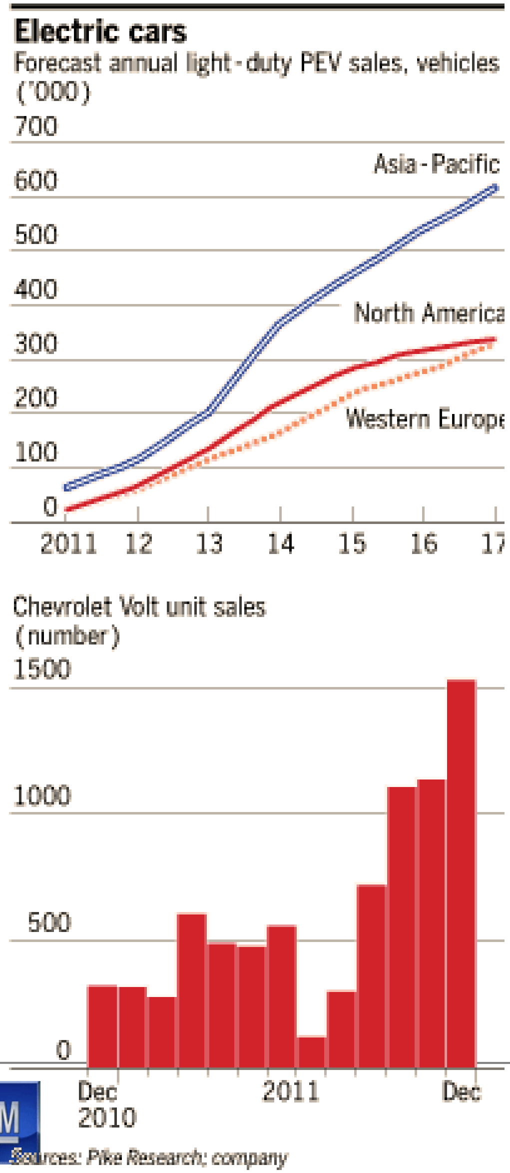
March 1, 2012

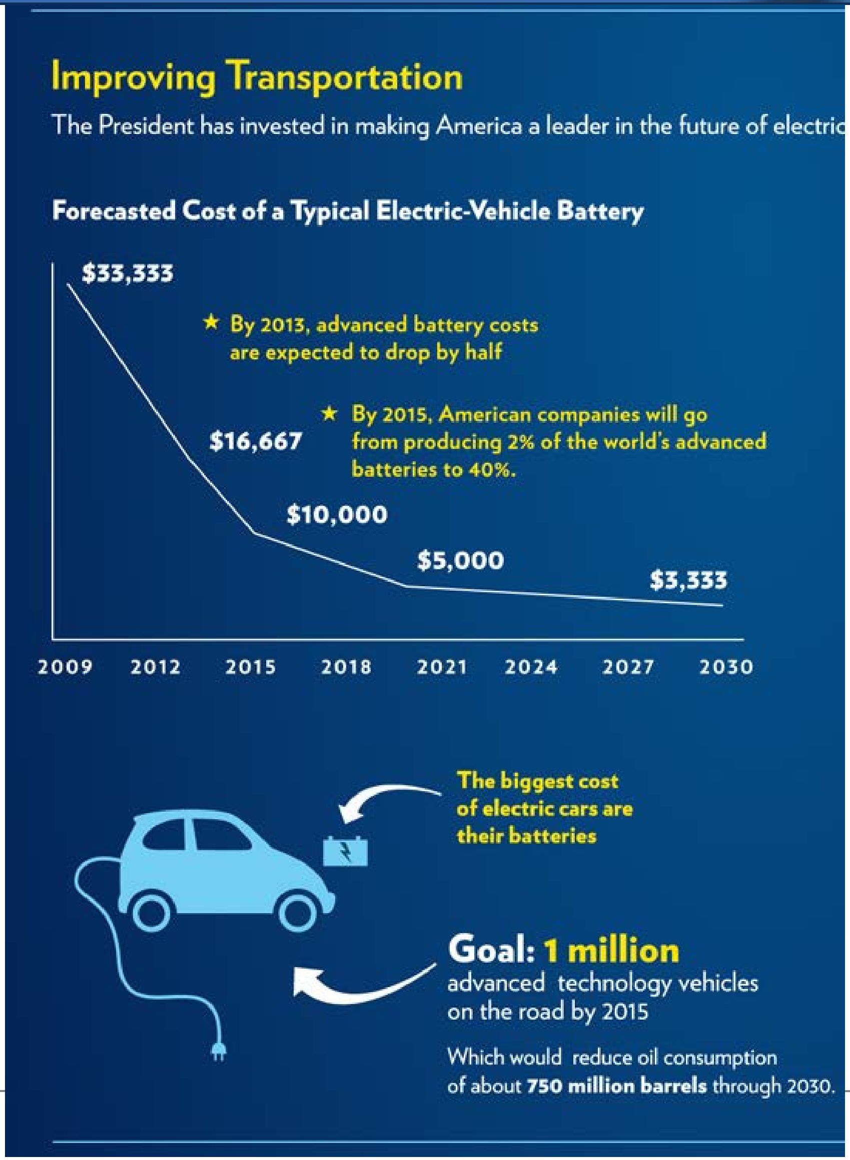
Houston, TX

Future of Automotive Transportation



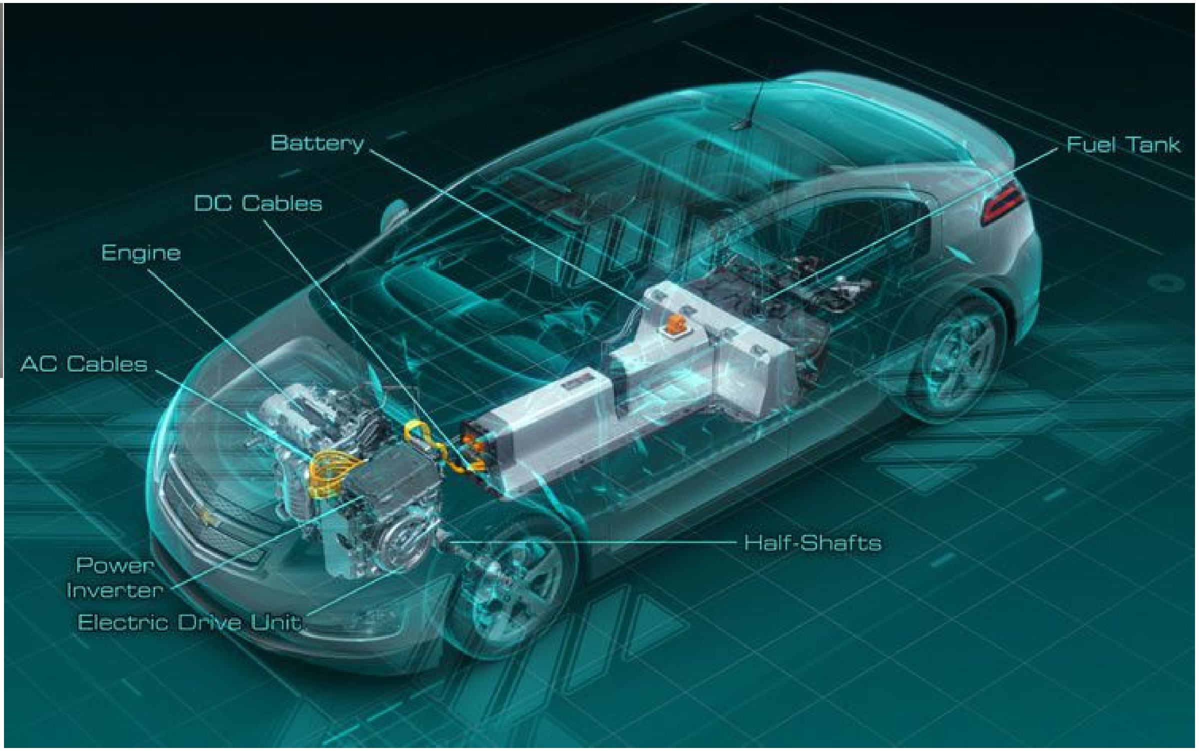
Future of Automotive Manufacturing



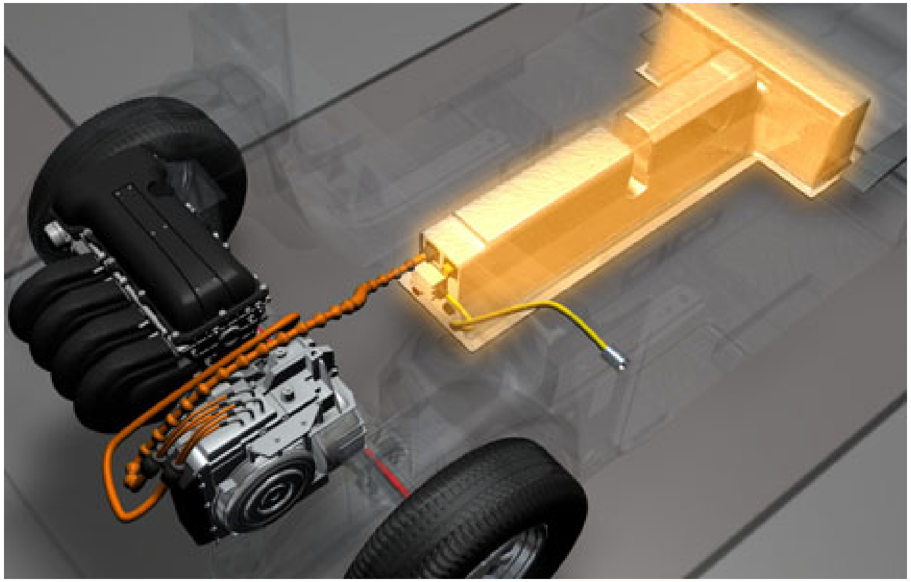


Future of Automotive Powertrain Technology: Chevy Volt

"The 2011 Chevrolet Volt is in the vanguard of the auto industry's shift from the petroleum-based model…to the electrified model.
With its new Voltec propulsion system, GM…brings a unique approach..." [SAE, 2011]



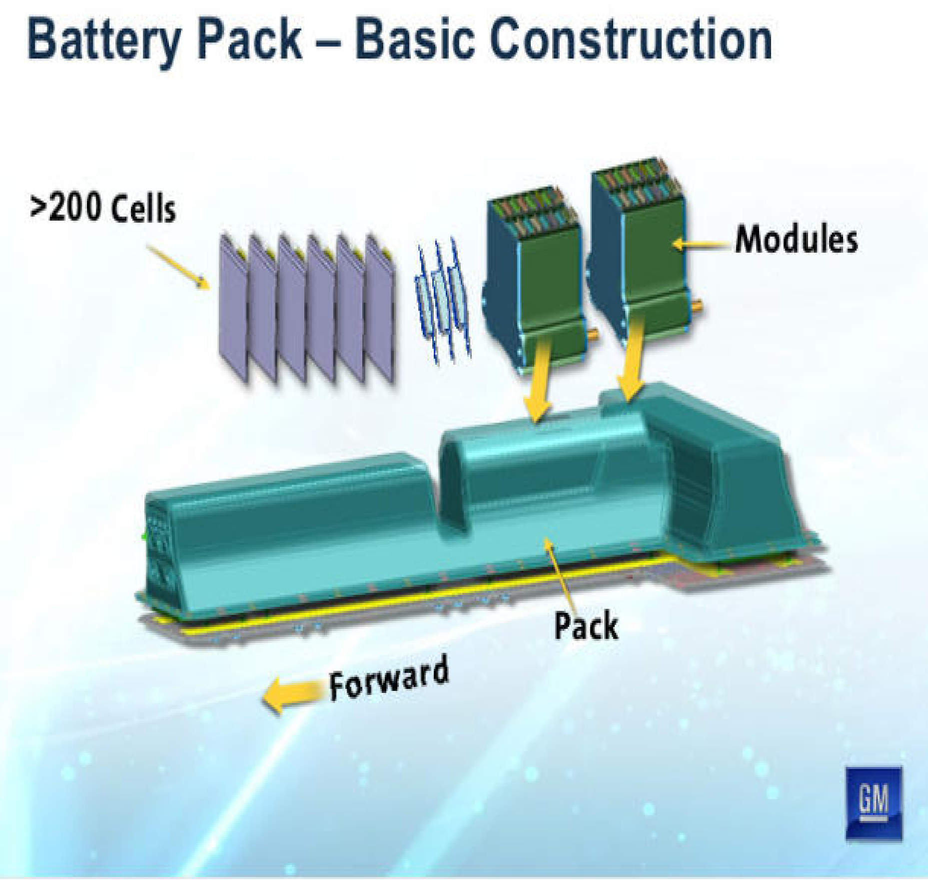
Voltec Powertrain



The hart of Voltec powertrain: Li-ion Battery

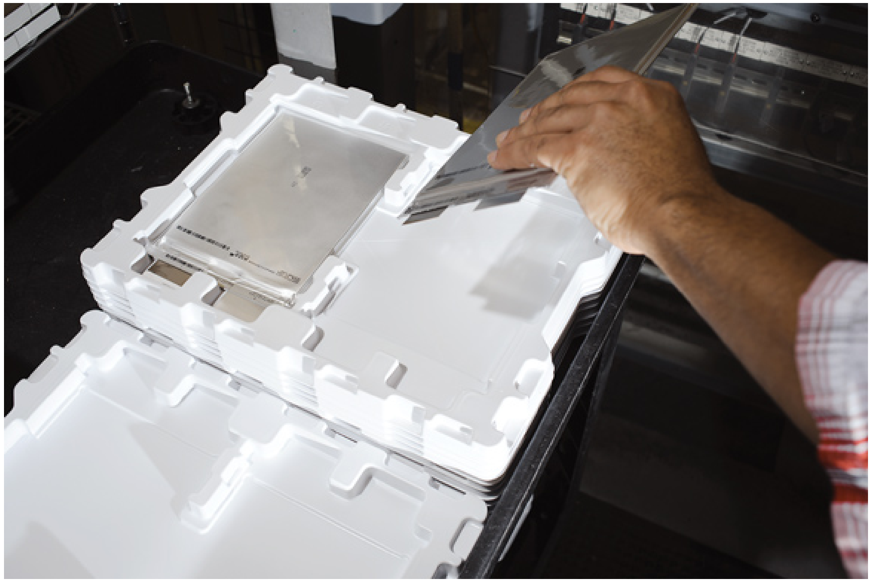
GM

Voltec Battery Design



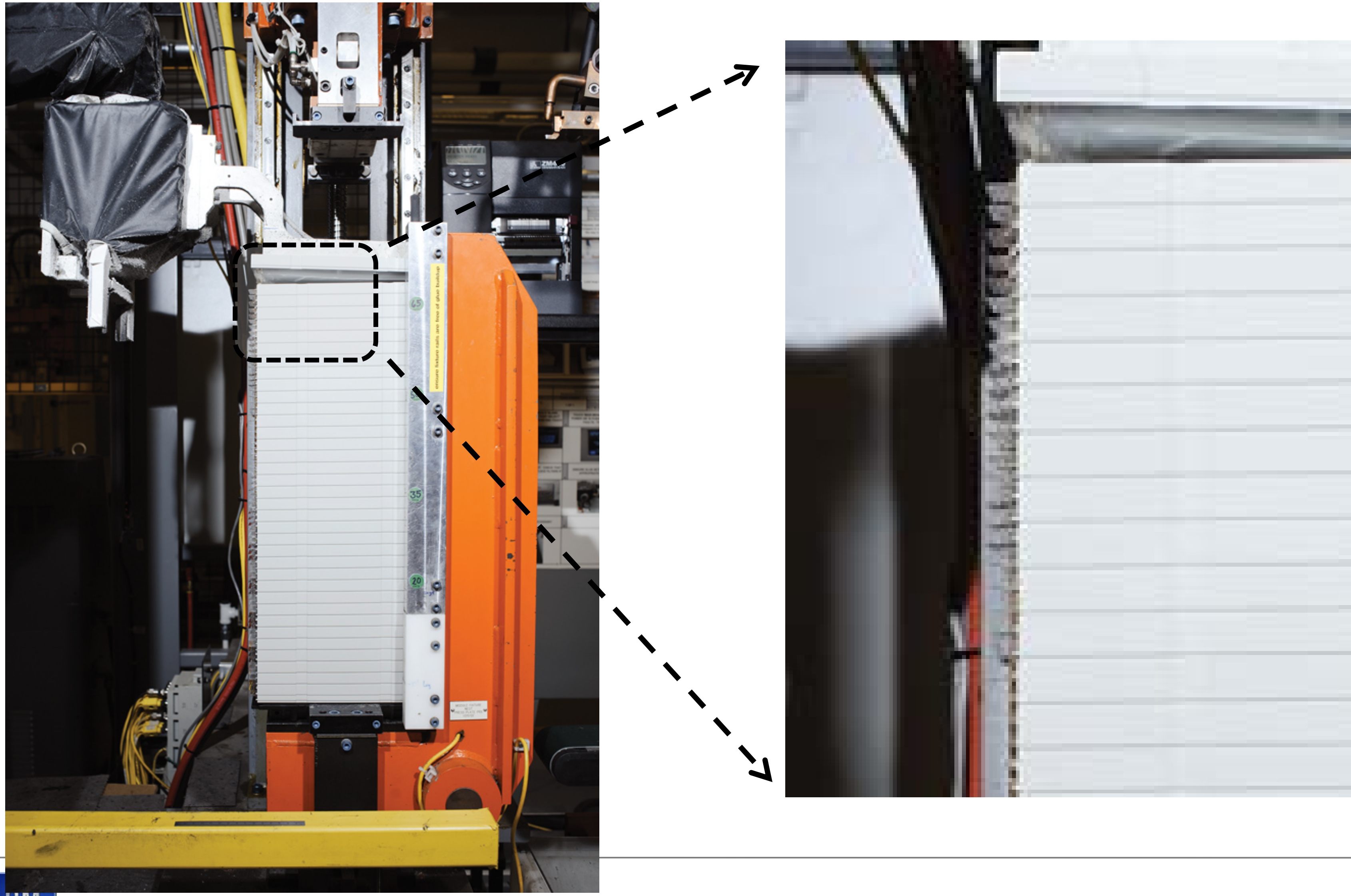
Battery Management System

Automotive Li-ion Battery "Cell"

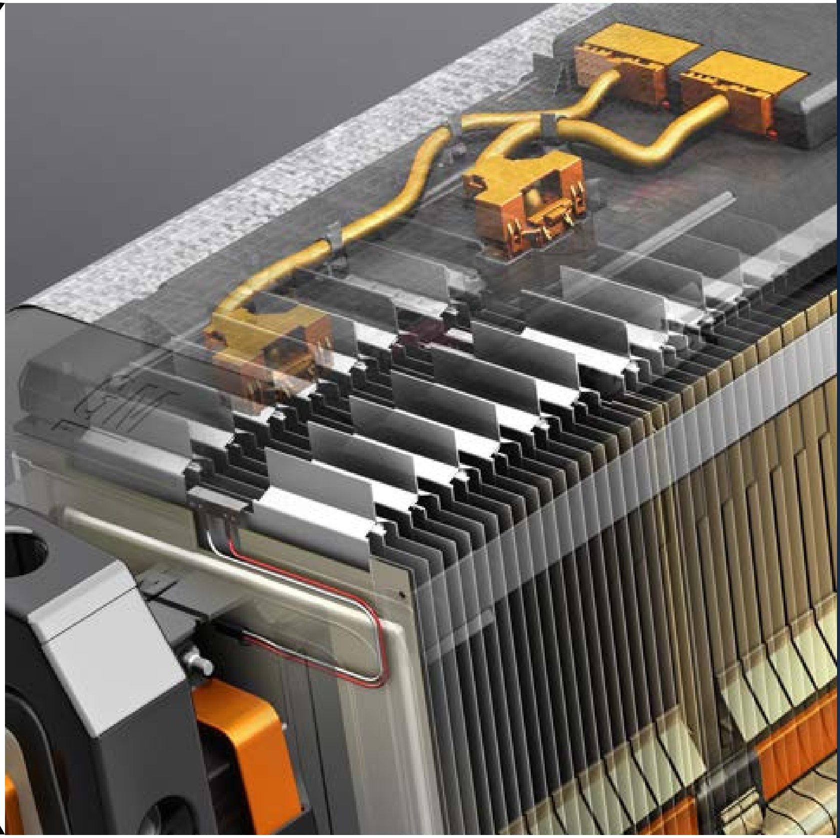


Courtesy MIT TechReview

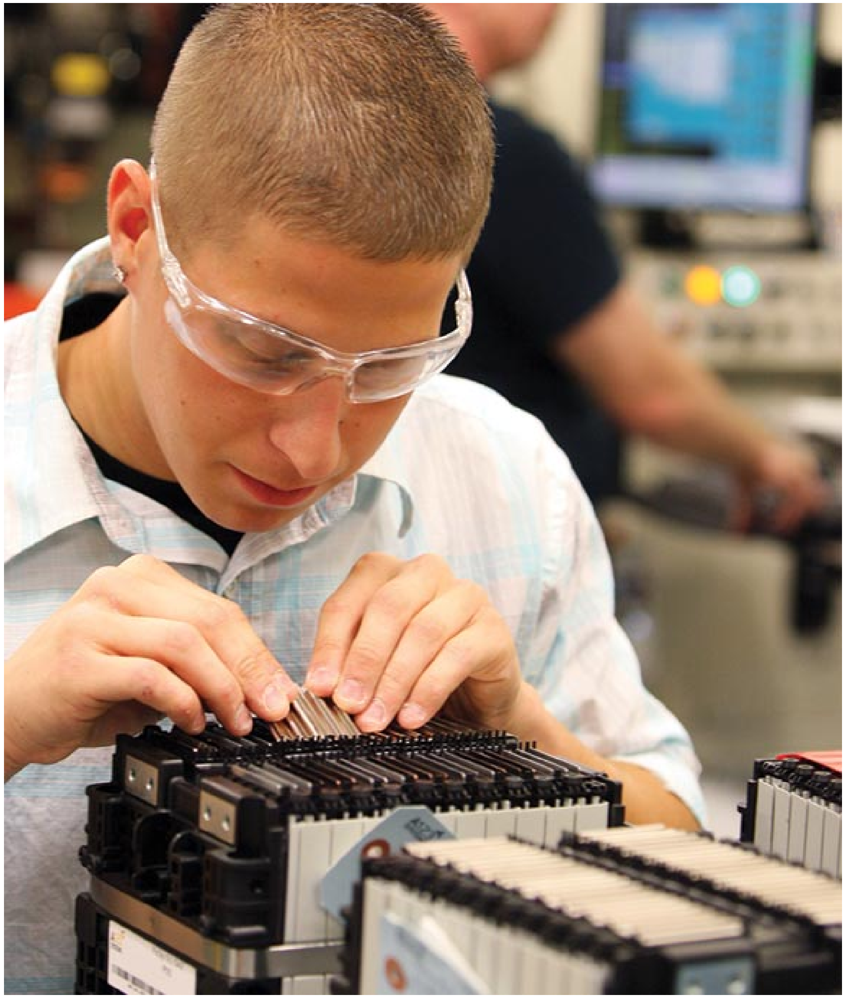
Battery Assembly: Stacking Operation



Assembled Battery Pack



Installation of Interconnects



Ultrasonic Welding Is Used for Battery Assembly

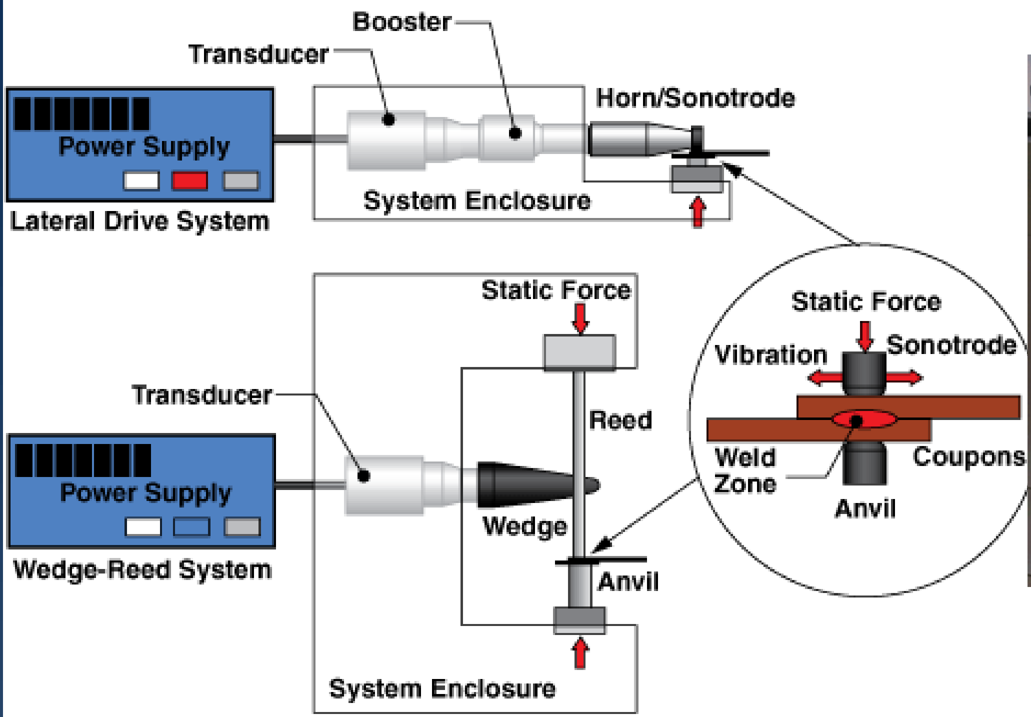
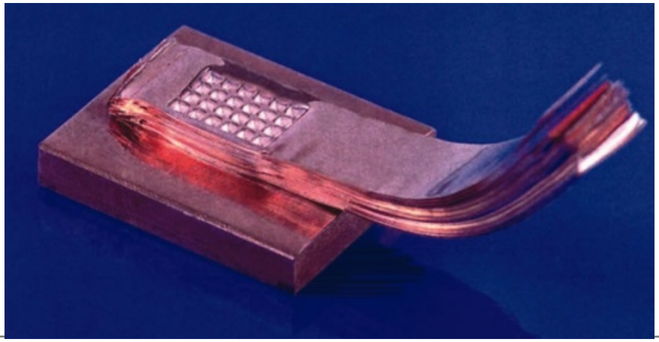
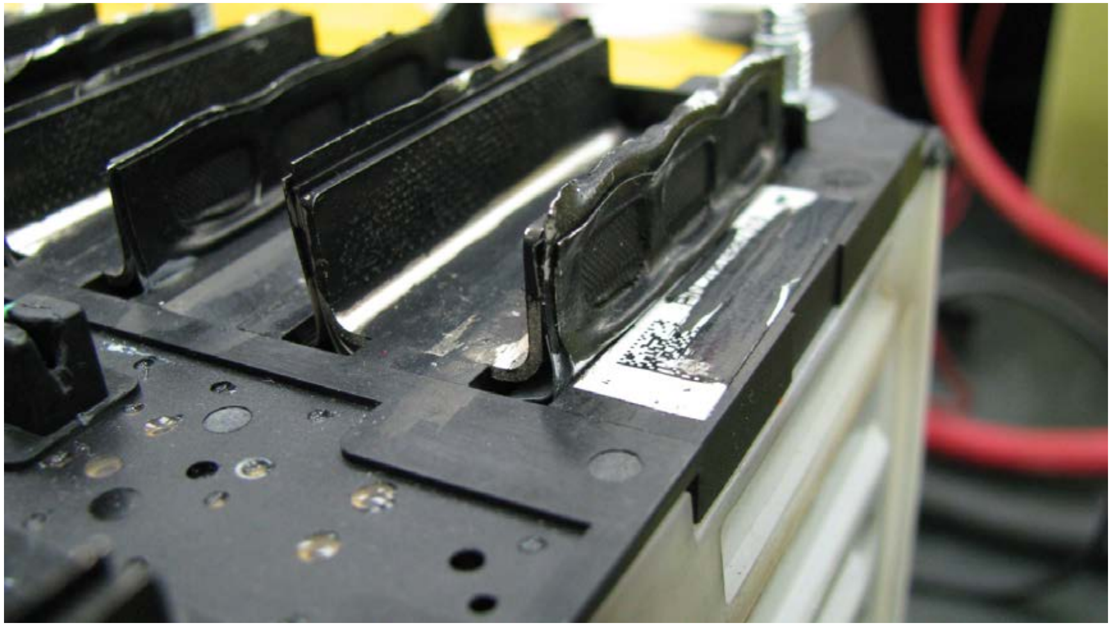


Photo courtesy of EWI



Voltec Battery Joints

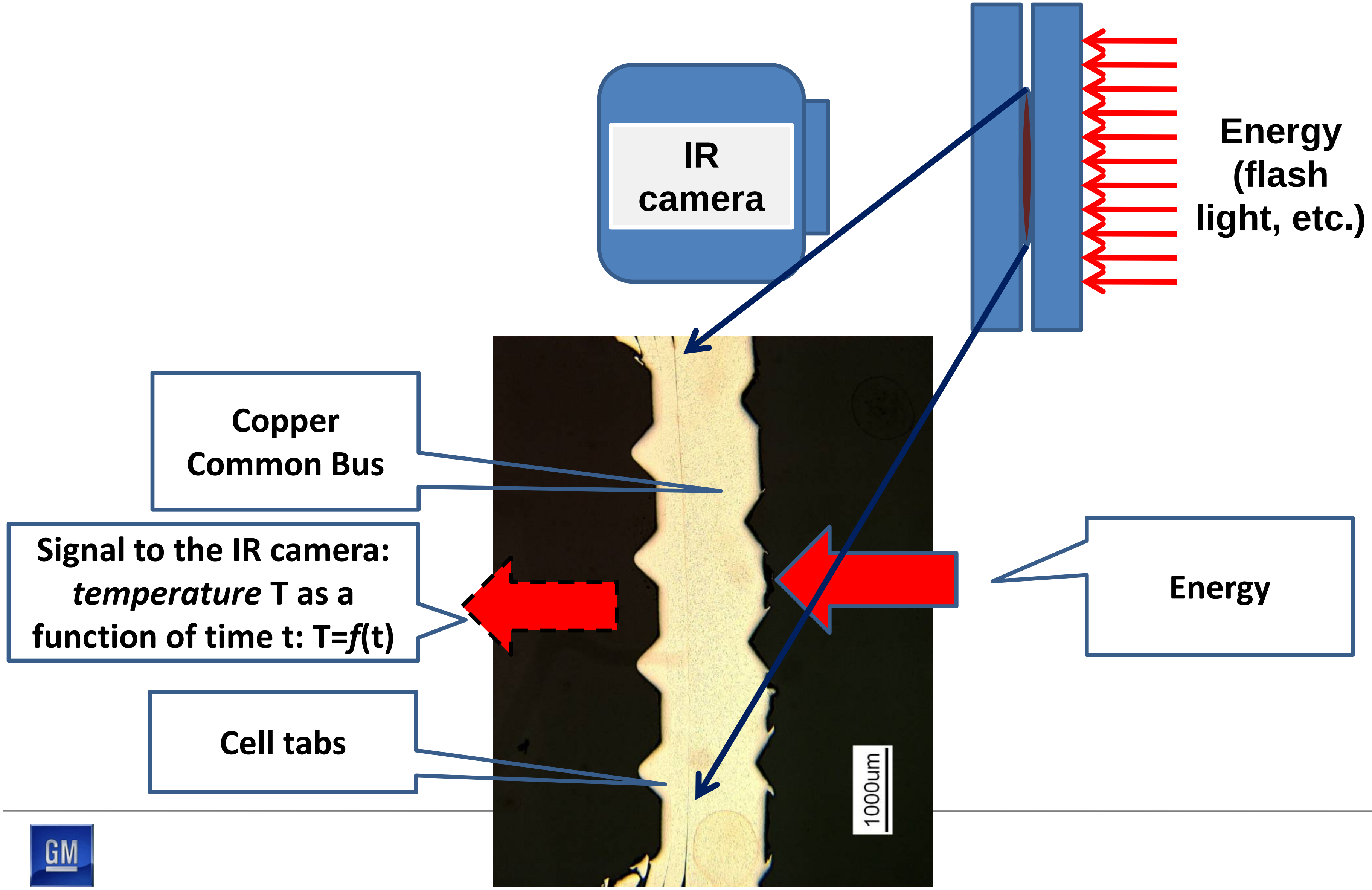


Four parts (three cell tabs and a common bus) per joint, three interfaces, dissimilar metals: aluminum and copper.
Each battery = 200 welds, multiple automated welding stations, high production rate.
Each interface has to be <u>good</u>!

Novel NDE Techniques Developed In-House

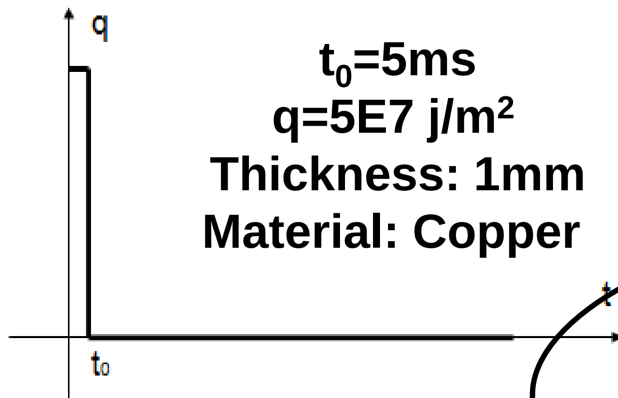
- **Active and Passive Flash Thermography NDE**
- **Shearographic NDE with Vibration Excitation**
  - Automated "pick test";
  - Good in finding concealed defects; can detect the extend of weld fused area
- **High-precision electrical resistance NDE:**
  - Tests functionality of the weld *and* its strength
  - A large number of welds can be measured quickly (~0.2 sec per measurement) and conveniently with one fixture

Flash Thermography NDE

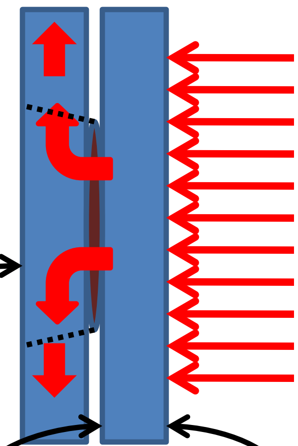


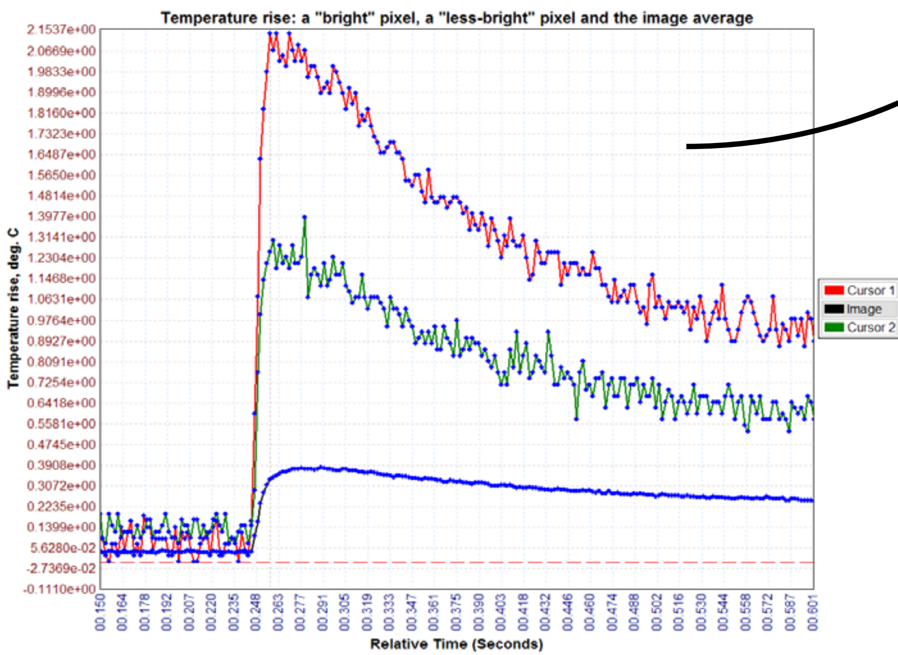
Thermal model

$$\begin{cases} \dfrac{\partial T}{\partial t} = a\dfrac{\partial^2 T}{\partial x^2} \qquad \left(a = {k}/{\rho c}\right) \\ T\big|_{t=0} = 0 \\ \dfrac{\partial T}{\partial x}\Big|_{x=0} = \begin{cases} {q}/{k}, & 0 \le t \le t_0 \\ 0, & t_0 \le t \end{cases} \\ \dfrac{\partial T}{\partial x}\Big|_{x=l} = 0 \end{cases}$$

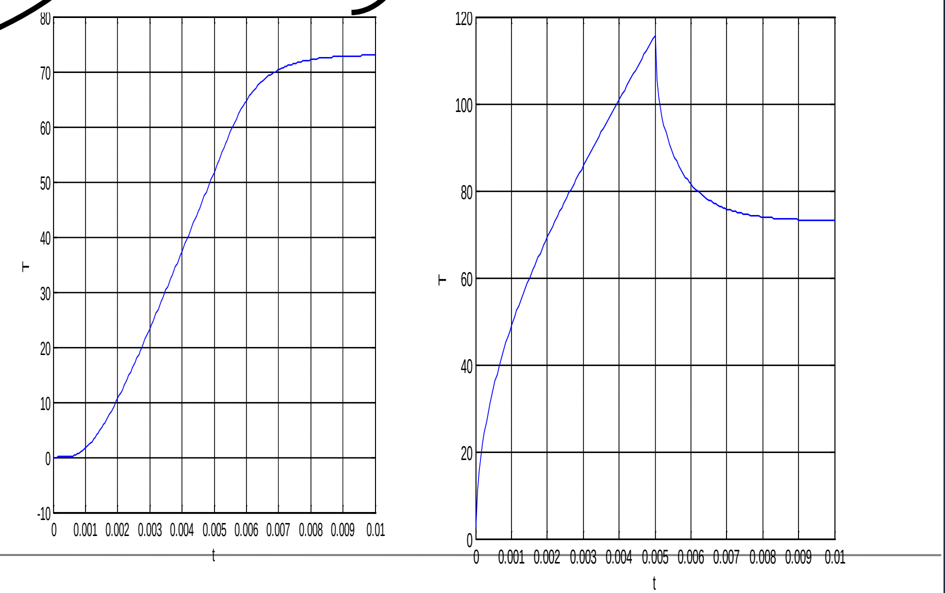


t_0=5ms
q=5E7 j/m^2
Thickness: 1mm
Material: Copper

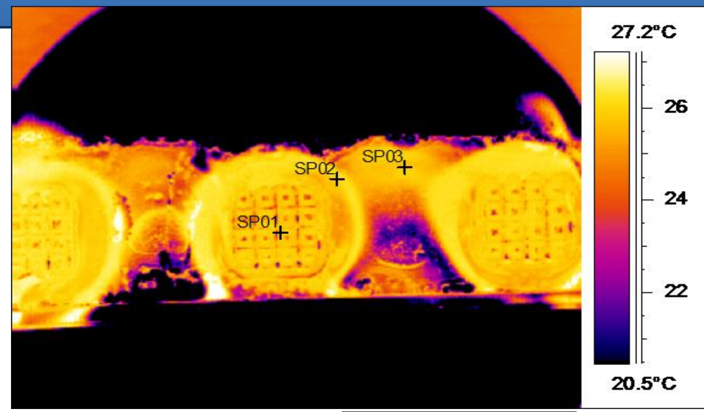


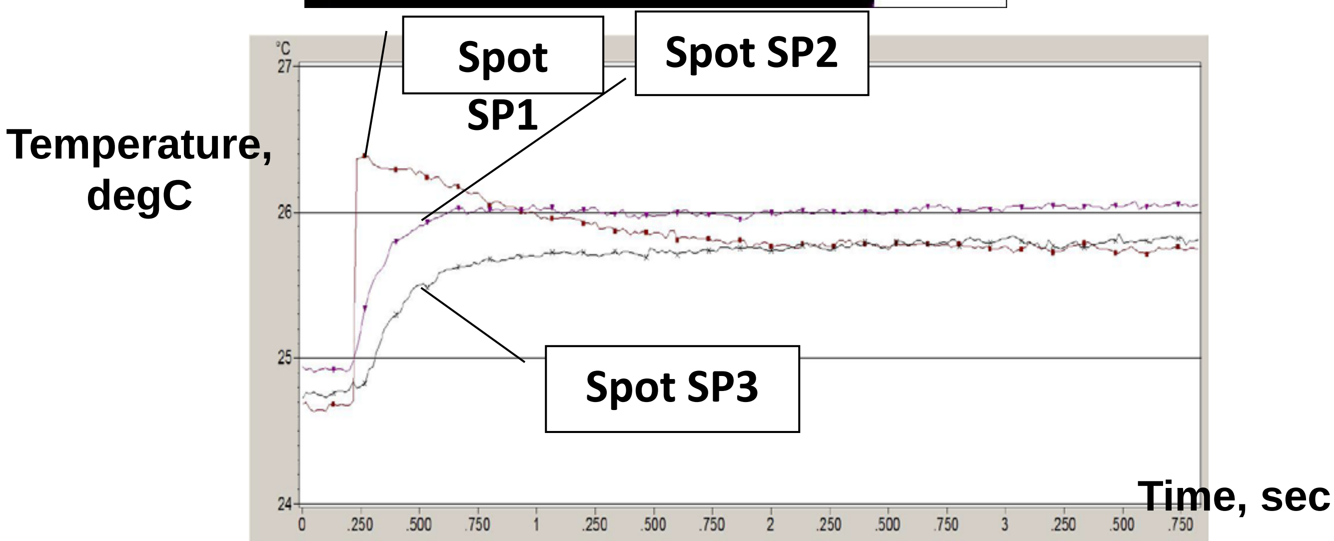


Temperature



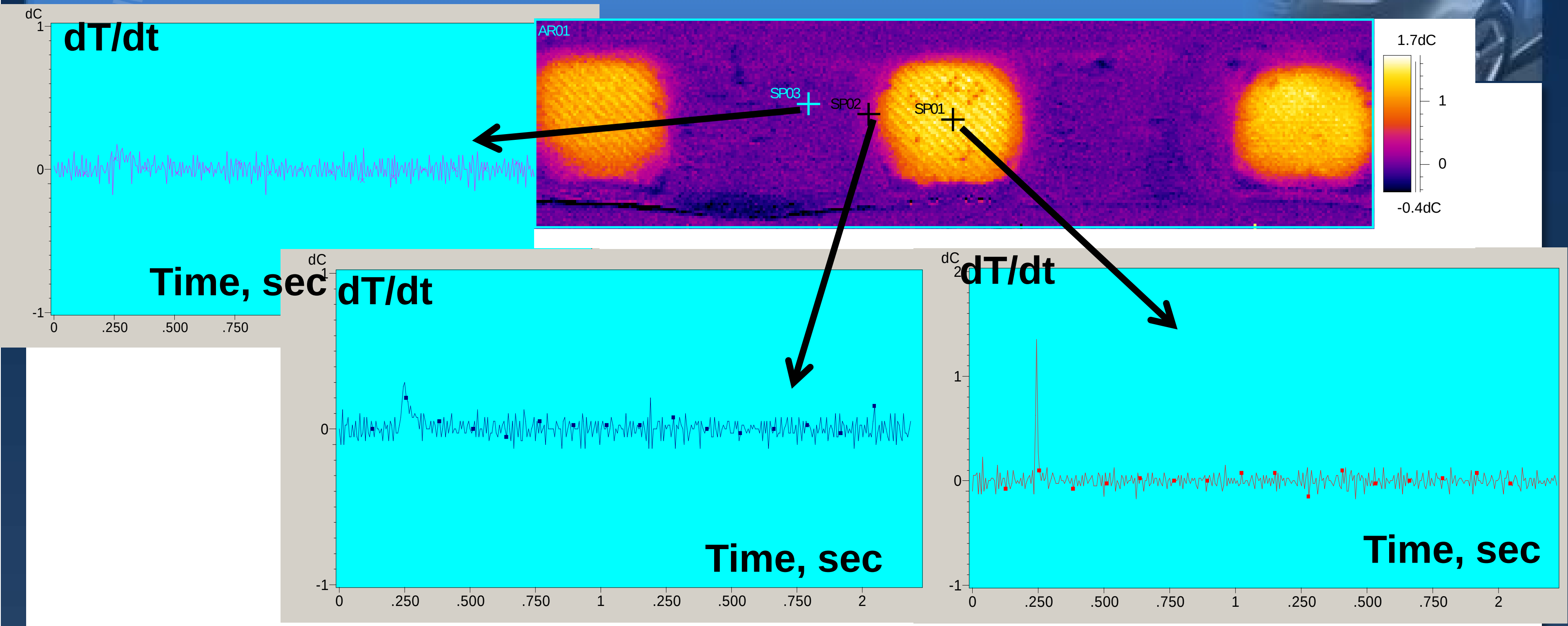
How to detect the fused area





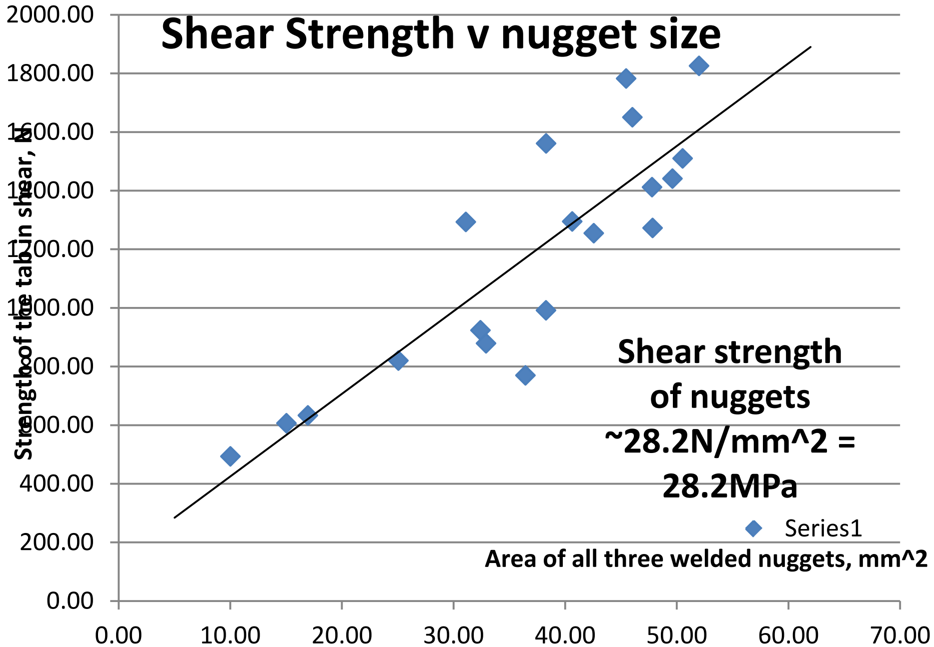
The temperature rise is more rapid in the fused area.

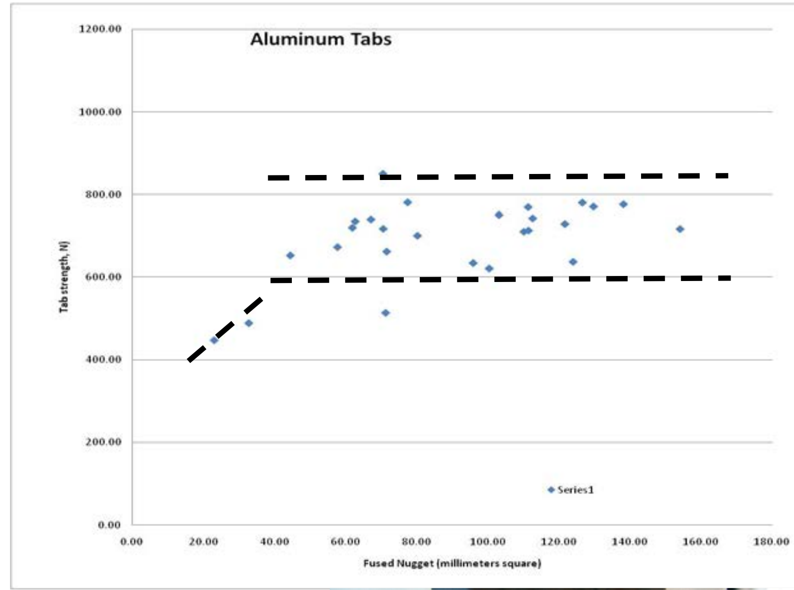
Results of differentiation with regard to time

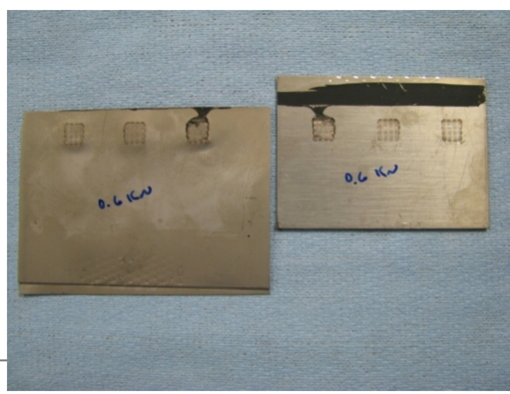


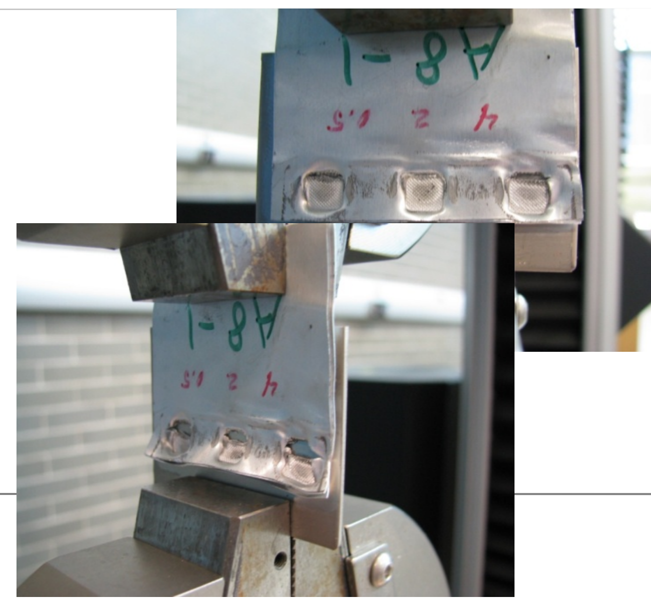
Post-processing: differentiating with respect to time in each point (pixel) to find total fused area.

Weld strength correlates with the size of the "nugget" …unless the joint fails elsewhere



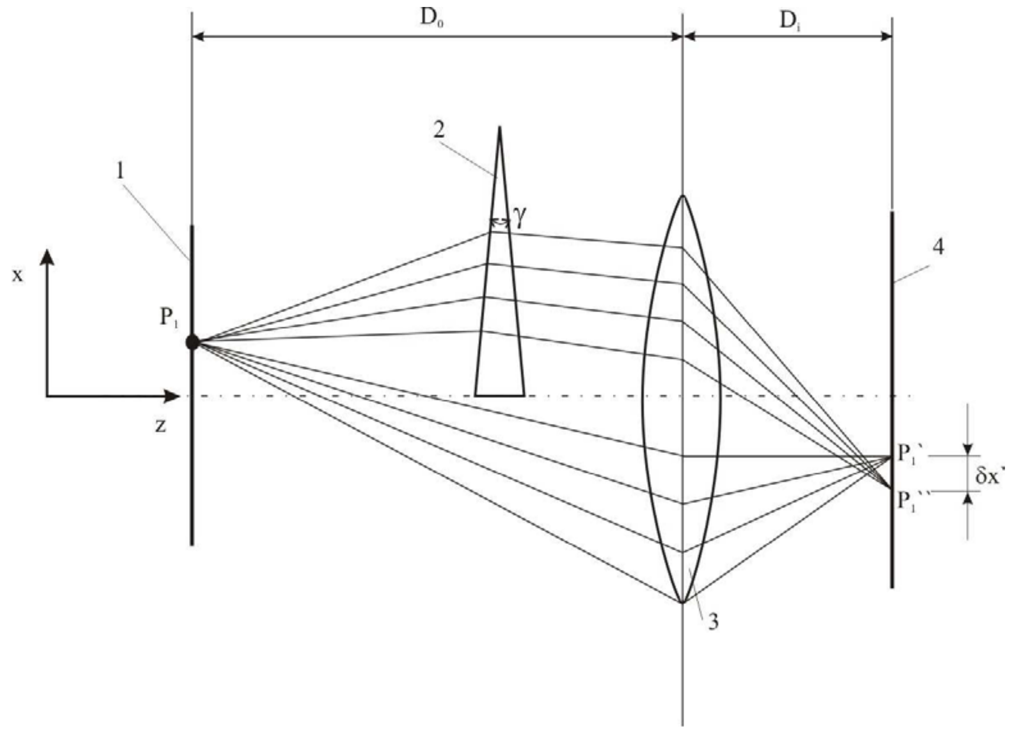




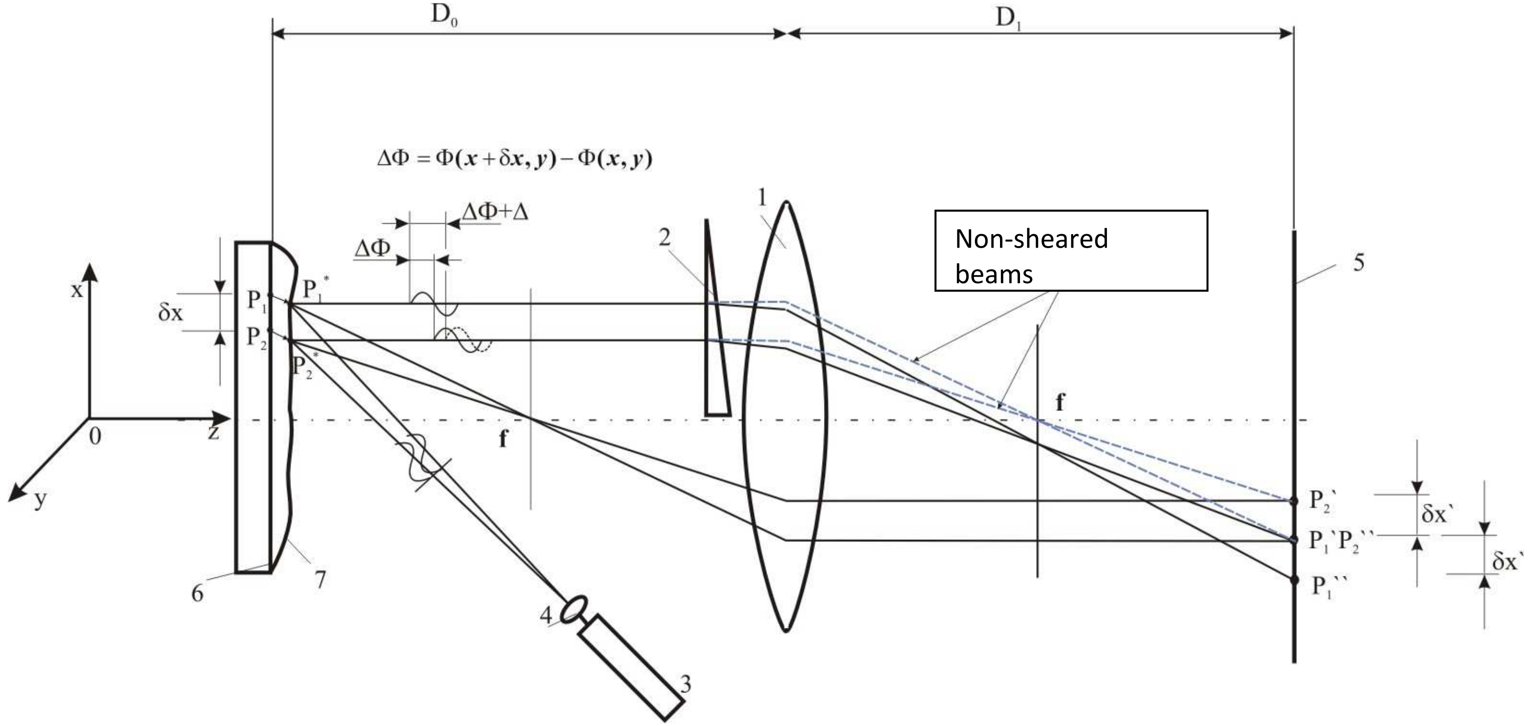


GM

What is a shearographic camera?



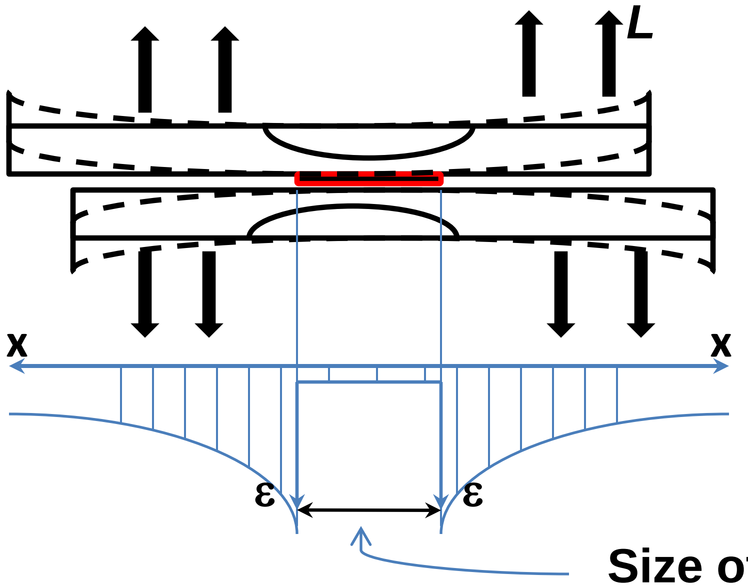
Formation of a shearographic pattern



Two superimposed images are formed: a *sheared* image(s) of the object and the superimposed image of the fringes containing information about surface strains.

Shearography-based NDE with vibration excitation

- When vibration is applied to an assembly, a pattern of (elastic) strains forms around the weld



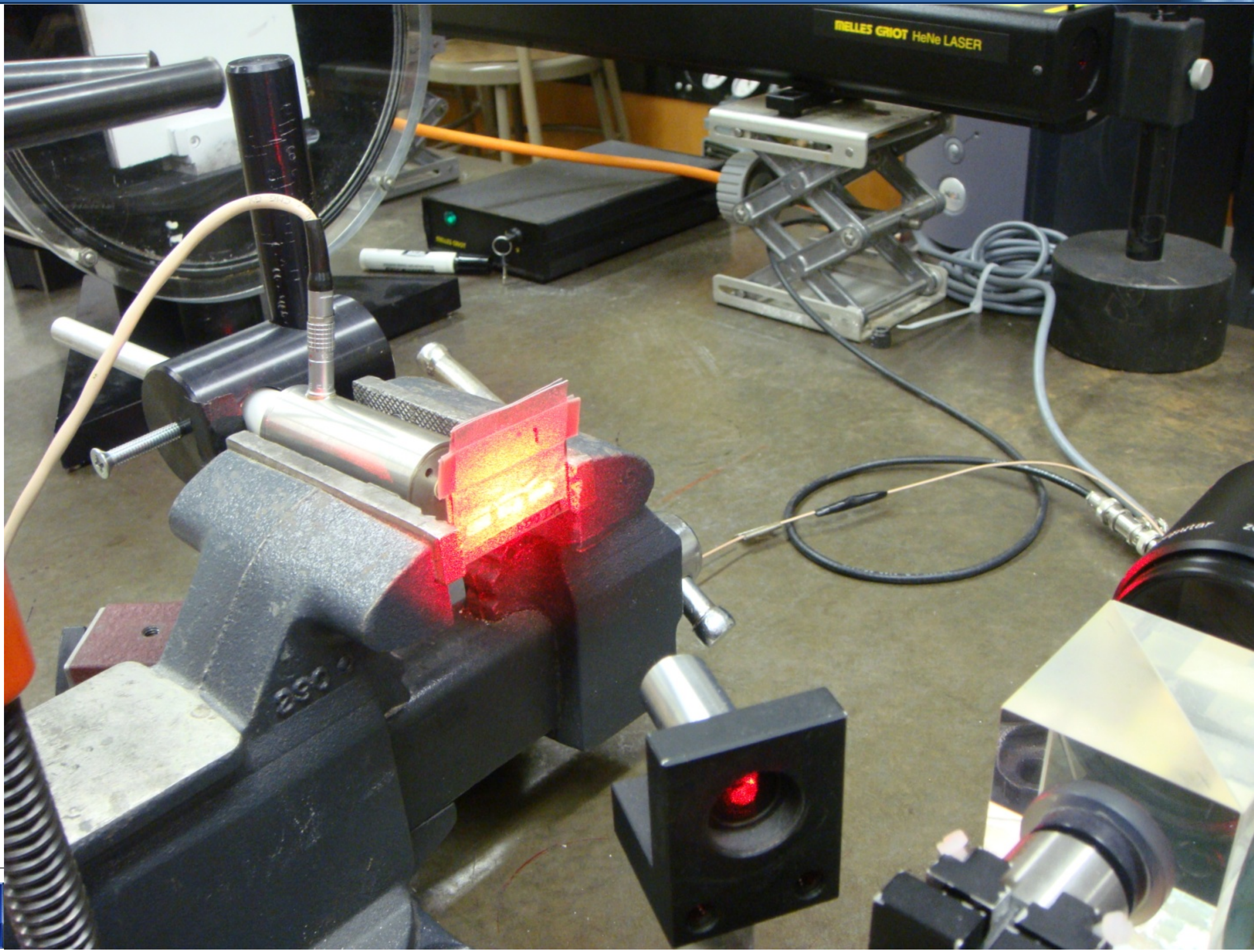
A schematic of a spot weld, loaded with loads *L*

Pattern of strains ε (generally, a 3D field, becomes 2D on the surface)

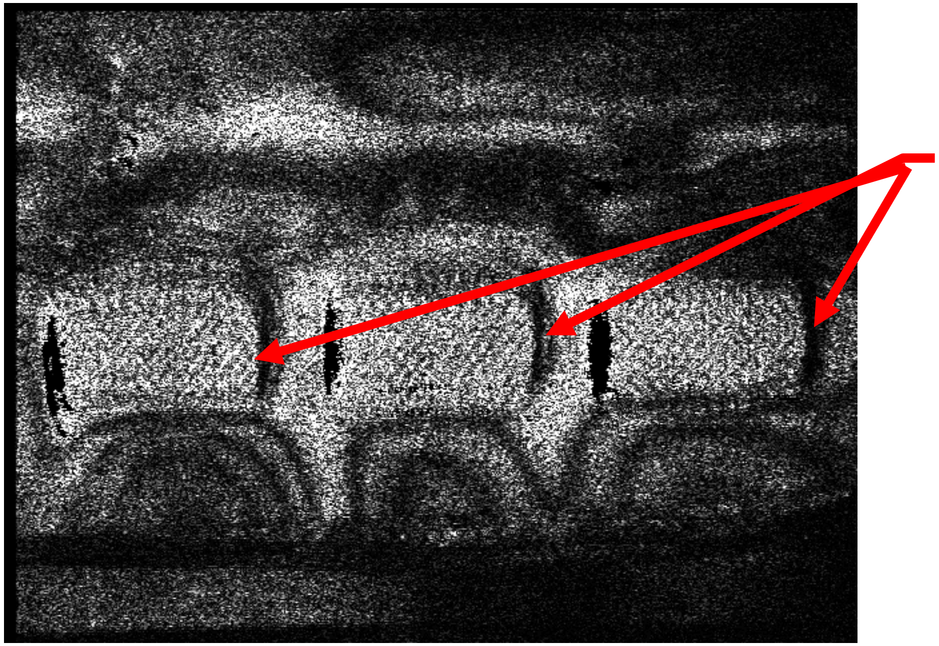
Size of the weld nugget

Image recognition is used to detect weld defects.
FEM model is used to determine the size of the fused area from the strain pattern ("inverse problem").

Sample with three welds, illuminated by a laser

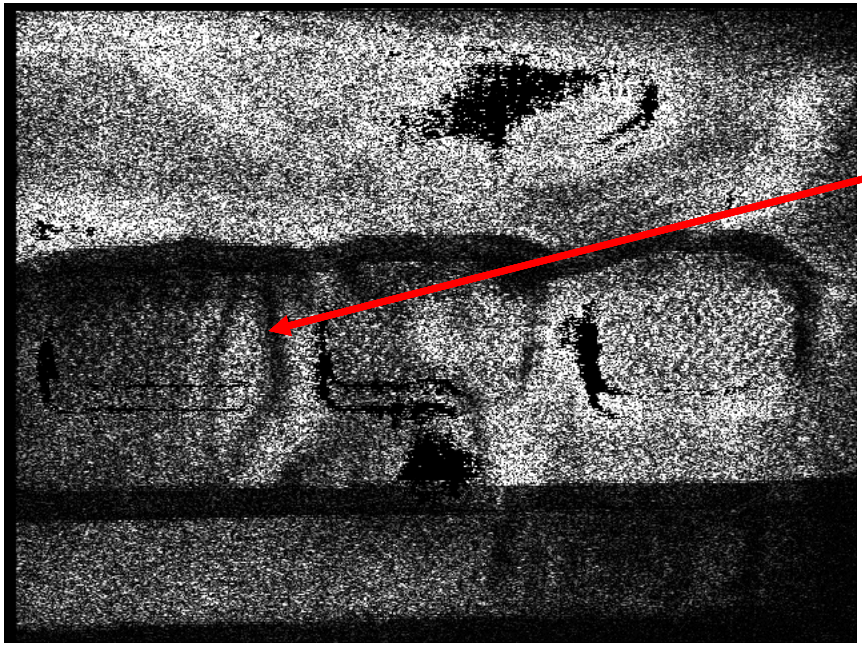


Good weld. Excitation frequency is 9.3KHz



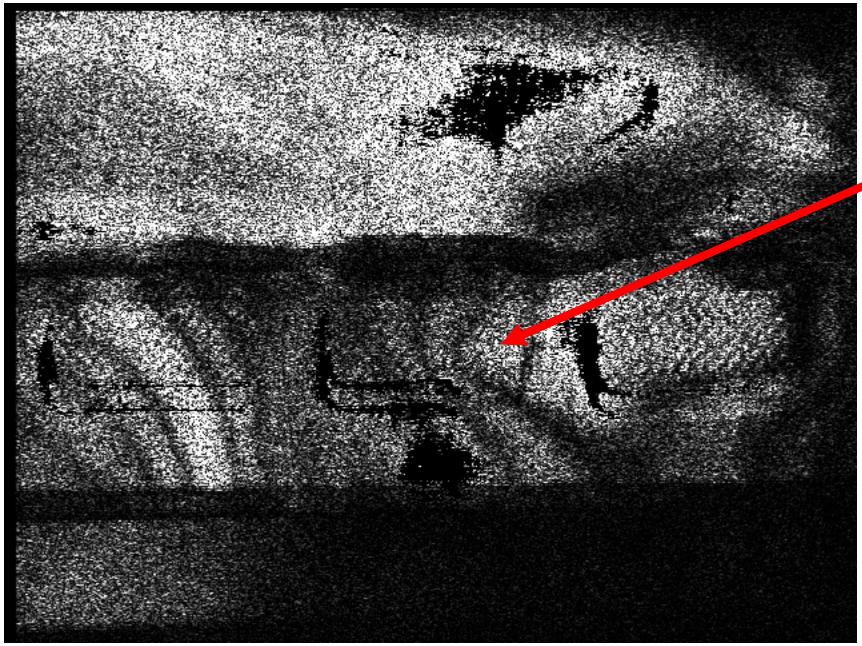
3 good welds.

Defective weld. Excitation frequency is 2.5KHz



No weld nugget

Defective weld. Excitation frequency is 5KHz



Partial weld

High-precision electrical resistance NDE

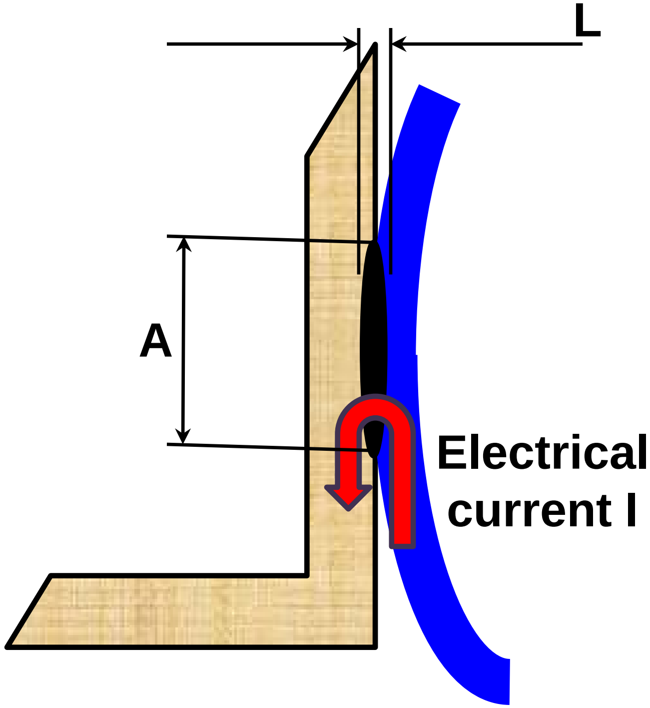
Electrical Resistance *R* and Strength *S* of a Weld:

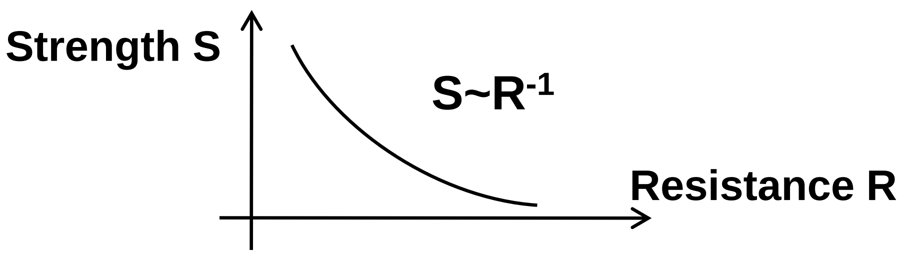
- **area *A***
- **Resistivity ρ**
- **Interface "length" *L***
- **Interface ultimate strength σ_u**

$$S = \sigma_u A$$

$$R = \rho \frac{L}{A}$$

$$Therefore: S \propto R^{-1}$$





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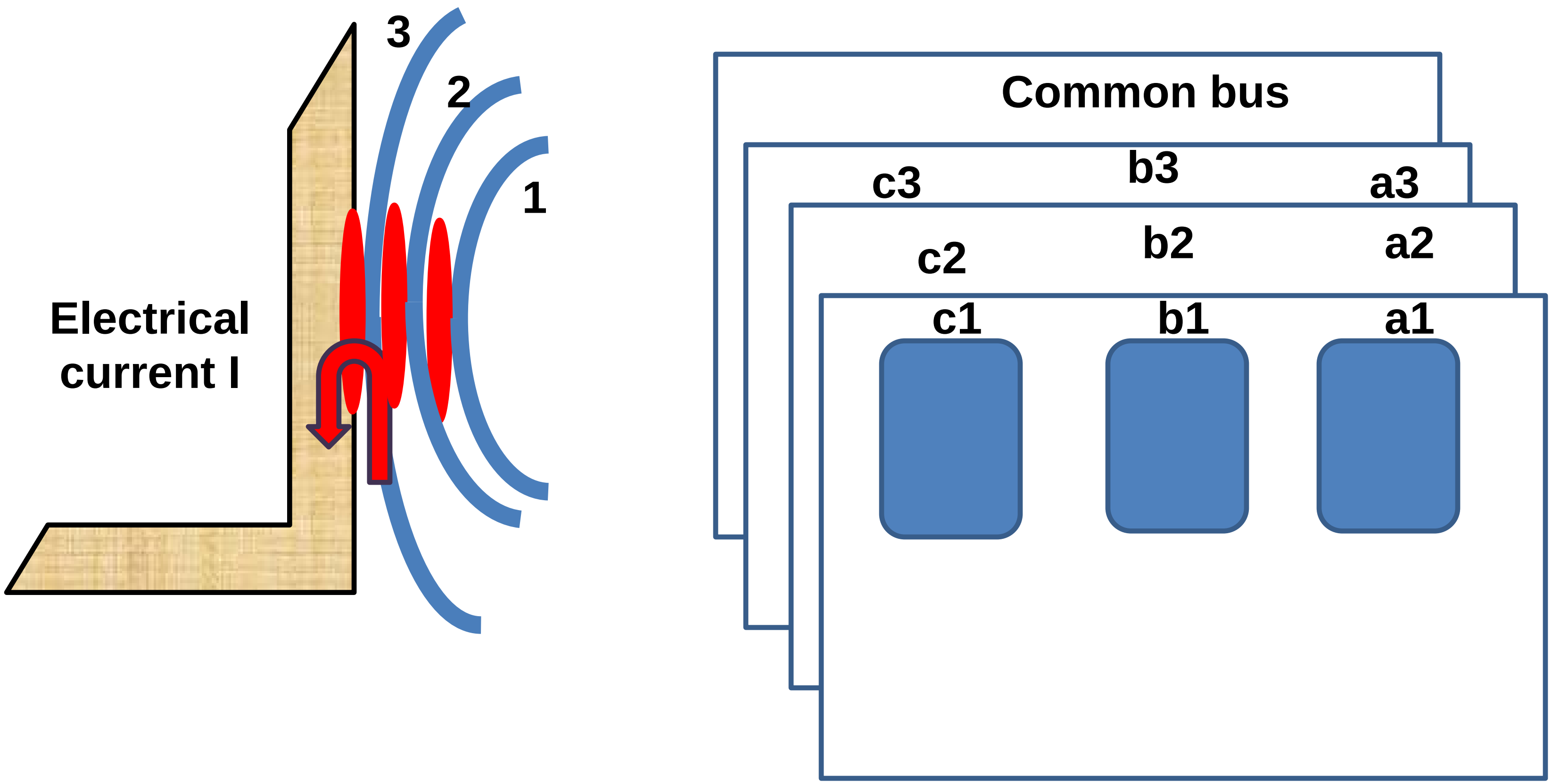
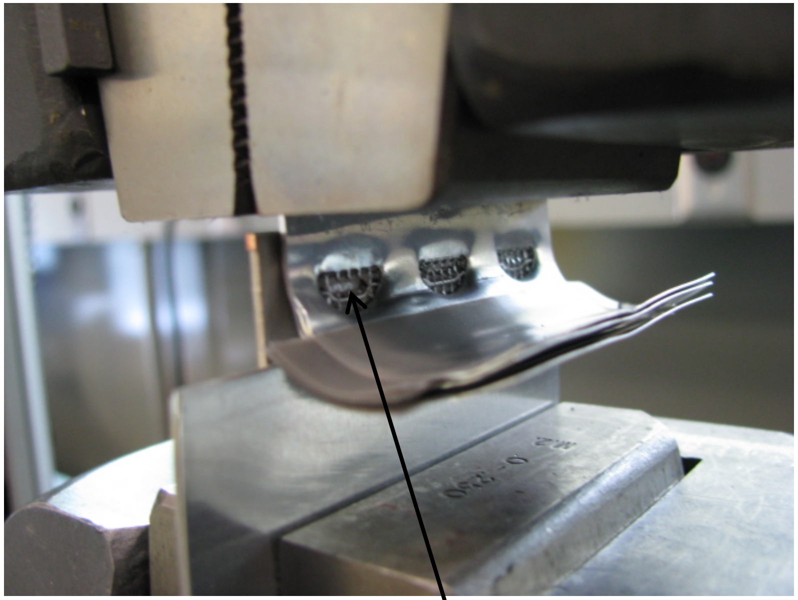
The real weld is more complicated…

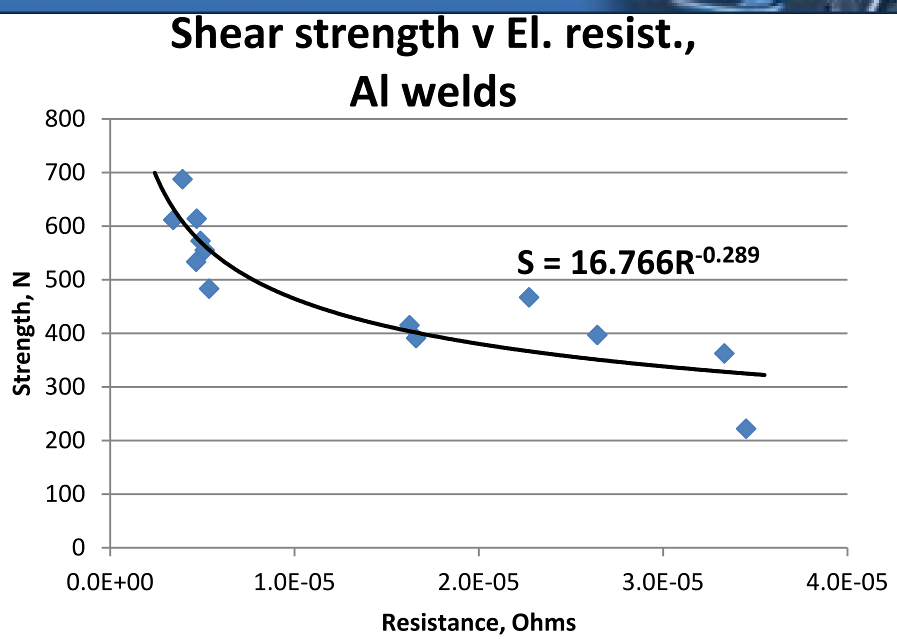


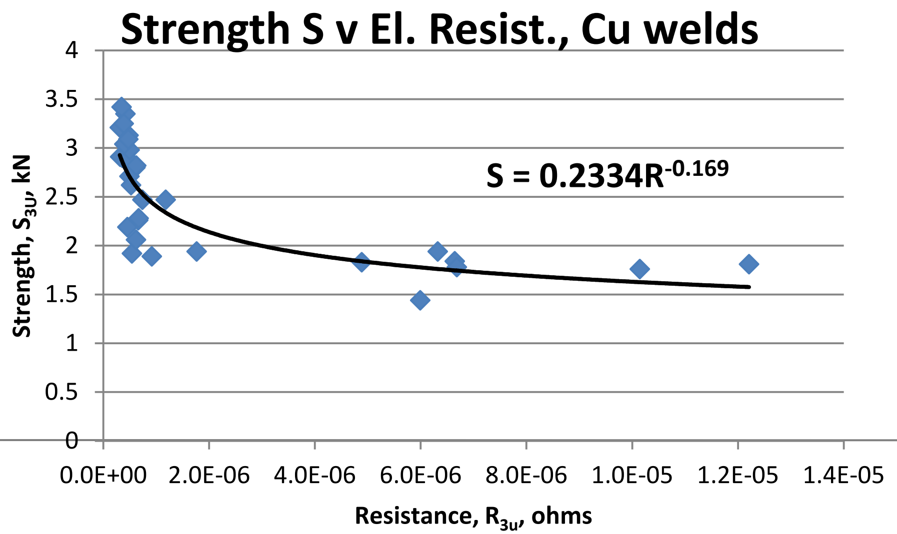
Correlation: Strength v Resistance

Strength testing of welded samples



Tearing through the weld





Comparison of the developed NDE methods

Method	Advantages	Disadvantages
Thermography	The only method to measure the size of the fused area of multi-ply welds Non-contact	Requires high-power energy input → needs protection on production floor.
Shearography	Measures the true extent of a fused area; may uncover concealed defects	Requires: •high-resolution shearographic cameras •sophisticated image analysis and software
Precision Electrical Resistance NDE	Measures the main functional parameter of the weld. Can monitor welds throughout the battery life.	Requires contact fixture; needs a reliable contact with joints

Automotive NDE Needs

- **Traditional NDE areas:**
  - NDE of safety-critical lightweight automotive components
  - NDE of welding and joining
  - NDE of adhesive joints
  - NDE of spot welds (in selective applications)
- **New NDE applications:**
  - NDE of Li-ion batteries and cells, in production and throughout the life
  - Inexpensive NDE methods for composite materials
  - NDE of joints of dissimilar materials, composites
  - Life monitoring of composite structures.
- **Production process control**

THANK YOU FOR YOUR ATTENTION!

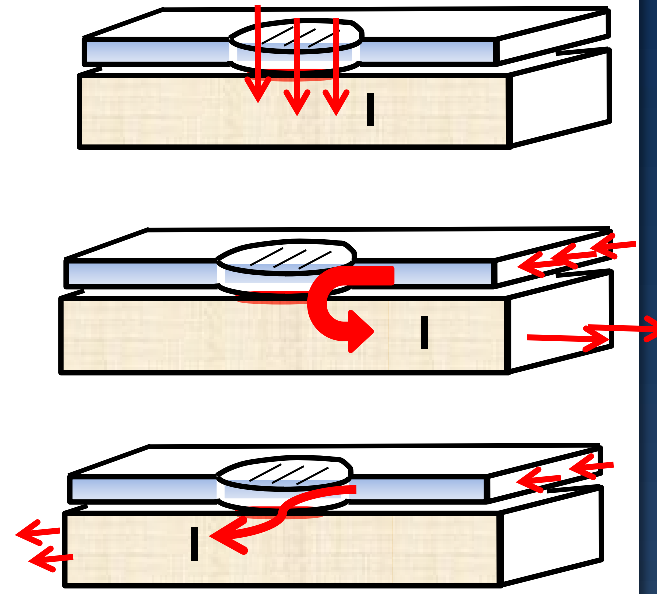
BACKUP SLIDES

Automotive NDE Needs

- **Traditional NDE areas:**
  - NDE of safety-critical lightweight automotive components
  - NDE of welding and joining, particular of dissimilar materials and composites
  - NDE of adhesive joints
- **New NDE applications:**
  - NDE of Li-ion batteries and cells, in production and throughout the life
  - Inexpensive NDE methods for composite materials
    - Infrared, shearography, vibro-thermography, x-ray, CT, ultrasonic, eddy current; combination, new NDE techniques
  - Life monitoring of composite structures.
    - Fluorescent dyes/penetrants
    - Electrical methods
- **Process control in production**

High-precision electrical resistance NDE

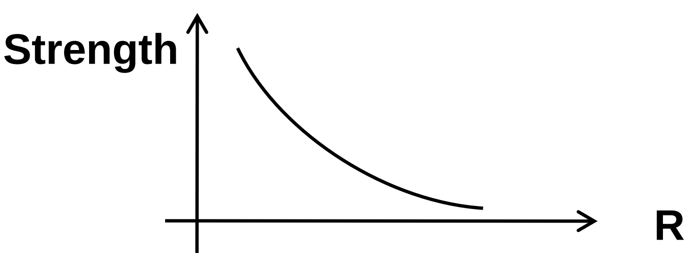
The electrical resistance of the weld depends on how the current is applied.



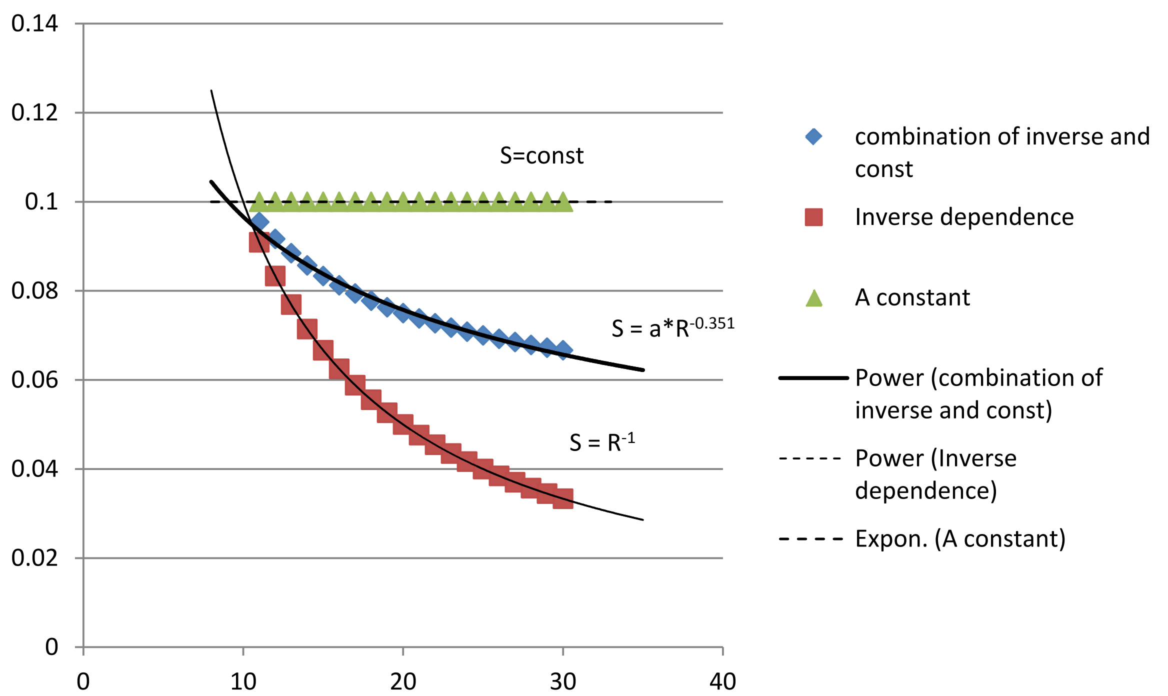
$$S = \sigma_u A$$

$$R = \rho \frac{L}{A}$$

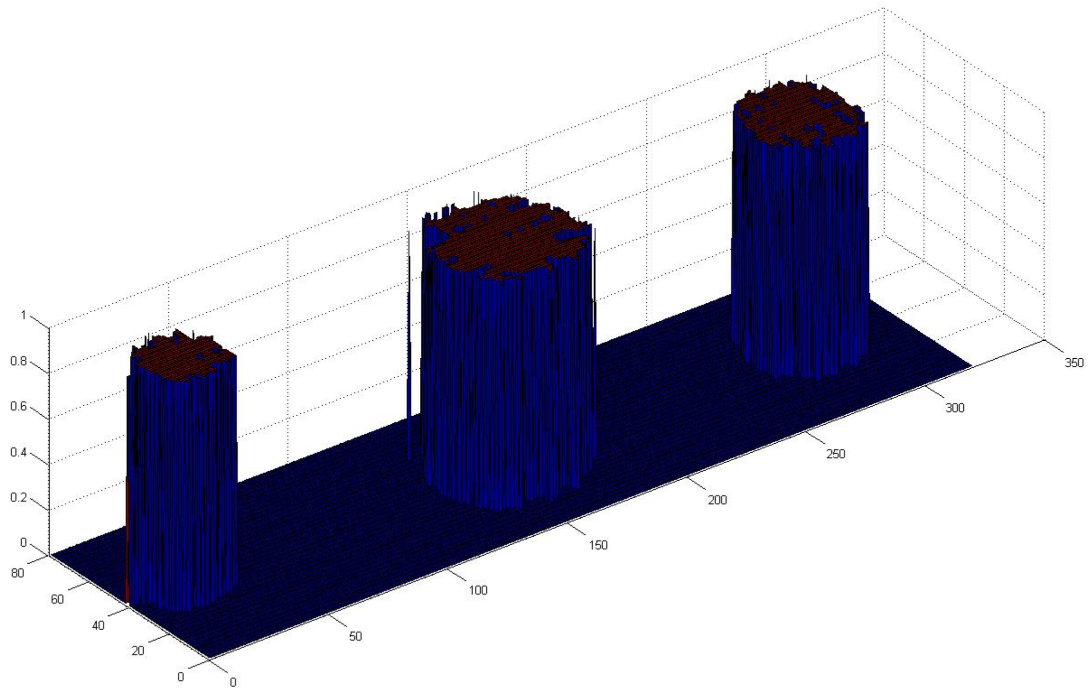
$$Therefore: S \propto R^{-1}$$



Explanation of lower power



The signal can be digitized (made 0 or 1) and counted



- **Done with Matlab**
- **Each pixel is a square with dimensions (approximately):**
  - 100μ X 100μ, with area $A=10^{-2}$ mm^2

- The entire module can fit in the field of view of IR camera…
- …but heat can be applied one joint at a time